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Using Process Model to Support Design and Re-configuration of an Airport Terminal

Sarah Shuchi
PhD Candidate, School of Design, Creative Industries Faculty, Queensland University of Technology, Australia

Robin Drogemuller
Professor, School of Design, Creative Industries Faculty, Queensland University of Technology, Australia

ABSTRACT:

The complex design process of airport terminal needs to support a wide range of changes in operational facilities for both usual and unusual/emergency events. Process model describes how activities within a process are connected and also states logical information flow of the various activities. The traditional design process overlooks the necessity of information flow from the process model to the actual building design, which needs to be considered as a integral part of building design. The current research introduced a generic method to obtain design related information from process model to incorporate with the design process. Appropriate integration of the process model prior to the design process uncovers the relationship exist between spaces and their relevant functions, which could be missed in the traditional design approach. The current paper examines the available Business Process Model (BPM) and generates modified Business Process Model (mBPM) of check-in facilities of Brisbane International airport. The information adopted from mBPM then transform into possible physical layout utilizing graph theory.

1 INTRODUCTION

The design process of an airport terminal should accommodate a wide range of changes in operations and facilities. Rapid growth in air travelling requires an airport terminal to increase the capacity and to optimize the processes of in-bound and out-bound facilities. Design approach of a complex system like airport terminal needs to recognize the relationships between the processes taking place within an airport terminal and the spaces required for smooth and efficient execution of those activities. Previous studies on space allocation for terminal buildings considering queuing theory approach (Ma, Kleinschmidt, Fookes, & Yarlagadda, 2011) attempted to establish relationships between passenger movement and terminal space. Researchers also focused on level of service standards to provide guidelines for the amount of space per passenger (Correia & Wirasinghe, 2007; de Neufville & Odoni, 2003; Mumayiz, 1990). Some other researchers investigated space allocation techniques specifically for commercial activities (Hsu & Chao, 2005). The significance of business process of various terminal activities, however, has not been recognized in the literature; this has rarely been accounted for to optimize the design process of airport terminals by allocating appropriate spaces based on the business processes.

Business process is a collection of activities or series of tasks designed to produce a specific output for a particular stakeholder (The Enterprise Architect, 2004). It implies a strong emphasis on how the work should be planned within an organization. Business Process Model (BPM) provides a conceptual network diagram of the processes within a facility using formal business process notations. BPM for the airport terminal activities, developed by the Business Process Management research team of the Airports of the Future (AotF), (AotF, 2010) illustrates passenger activities and states a logical control of information flow in various in-bound and out-bound operations within an airport terminal. Evaluation of business processes of airport operations could, therefore, provide important guidance towards planning and renovation of any airport terminal design. Analysis of process models of an airport terminal should provide important aspects to understand the role of passengers as well as should help to recognise the responsibility of airport stakeholders in the process. The current paper discusses the use of BPM for passenger activities to provide functional information to the designer in operational aspects and spatial layout.

The spatial allocation contributes to a design in two ways – by generating spatial layout that can appropriately respond to changing situation and by allowing to understand the correlation among particular spatial relation and their influences on physical solution (C. M. Eastman, 1975). Space layout planning is considered to be one of the most interesting and difficult of the all formal architectural design problems and has been examined by many researchers over a long period of time, dated back from 1963 (Jo & Gero, 1998). The ultimate goal of space layout planning is to optimize the layout of a certain building according the activity of the users. The application of graph theory to generate optimal layout of building was first initiated by Levin in 1964 (Grason, 1970). Use of graph theory enables a systemic progression from the required adjacencies towards achieving a space allocation model. (Hashimshony, Shaviv, & Wachman, 1980; Roth, Hashimshony, & Wachman, 1982). Further investigations based on the graph theory are also available in various literature. (Foulds & Tran, 1986; Grason, 1970 ; March & Steadman, 1971; Roth, et al., 1982).

This paper presents a conceptual method for utilizing the available process models to develop an initial architectural layout. The process models of Brisbane International Airport (BNE) have been examined, specifically the departure activities, as part of the current study. A generic method has been introduced to extract design related information from the available process models to incorporate with the design process. Figure 1 outlines the framework of the research methodology. In the first step, specific design aspects associated with an airport terminal design are identified where integration of business process model is expected to maximize the efficiency of the overall design process. The available process model of Brisbane International Airport is then turned into a modified Business Process Model (mBPM). mBPM is mapped into a graph using graph theory and further simplification could produce a planar graph for an airport terminal. The floor plan dual of the planar graph provides an initial architectural layout, which could eventually be transformed into dimensioned physical plan by incorporating appropriate relative importance for the involved business processes.

The benefit of applying this approach is that a range of BPM networks can be generated to match various options for structuring processes within a proposed or existing terminal building. When planning a new building this can ensure that the selected design can accommodate a range of process configurations before it is documented. This method can also be applied to existing airport terminals to assess how existing processes are accommodated, or to assess how a revised process network will impact on the use of the building. This could then provide a rational basis for discussion about the impacts of proposed changes in process and spatial requirements.

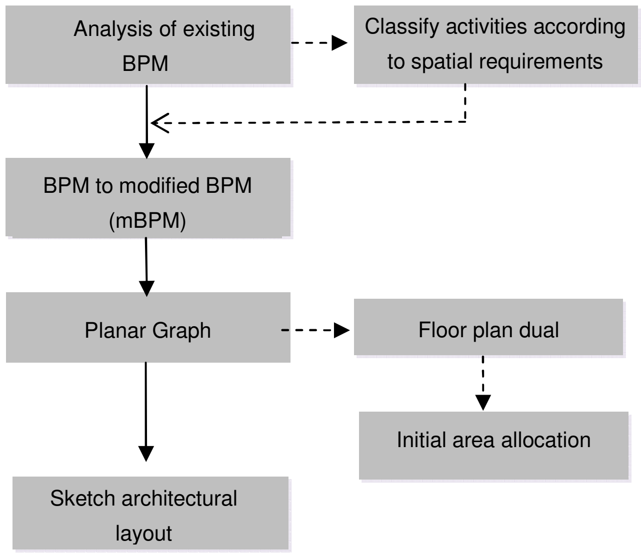

Figure 1. Research framework

2 UTILISATION OF BUSINESS PROCESS MODEL IN DESIGN PROCESSES

2.1 *Business process model in construction industry*

A process is a specific order of activities across time and place, with a beginning, an end, and clearly defined inputs and outputs. Process model describes how activities within a process are connected, ordered and structured (Lee, Eastman, & Sacks, 2007). It also illustrates activities and states logical information flow of the various activities within a process (Hammer, 2010). A business process is a collection of activities designed to produce a specific output for a particular customer or market. It implies a strong emphasis on how the work is to be done within an organization (The Enterprise Architect, 2004). Within this broad potential scope, the methods of defining process models and the model syntax can be highly varied.

Process models are gaining importance for studying operations within organizations generally in planning, re-engineering, automating or augmenting them. However, most of the previous research works mainly focused on business process reengineering in the construction industry. (C. Eastman, Teicholz, Sacks, & Liston, 2008; Lee, et al., 2007; Lee, Ham, & Park, 2011; Smith & Tardif, 2009) Previous research on process modelling explored the ways of making the effective use of process model information in deriving product model, where ‘product model’ refers to ‘data model’ or ‘information model’ in engineering. A research project developed within the North American Precast Concrete Industry (Lee, et al., 2011) aimed to integrate information within the companies that produce precast concrete and between a company and its suppliers, consultants, contractors and clients. Another research project conducted to develop national BIM standard for precast concrete used Business Process Modeling Notation (BPMN) for information exchange in building information modeling. According to Eastman et al (2008), existing process modelling methods and tools do not support extraction of information that can be used in various activities. The current available methods also do not support analytical validation of the process model and its information flow. There is enough room for research to exploit BPM in construction industry.

2.2 *Traditional building design and role of BPM*

Design process is a generic method that reveals how things are created and building design process is the scientific study of existing ideas to get some detailed solution(s) of a design (Idi, Khaidzir, & Zeari, 2011). Traditionally, building design process follows individual phases starting from initial concept drawings through to final detailed design and construction. There are number of notable models currently available for design process for building architecture (Lawson, 2005). The common idea behind all the design processes is to identify the sequence of distinct and identifiable activities in a predictable and logical order. According to Lawson (2005), designers must follow a rational order to progress from the first stages of the problem to the final solution. Figure 2 illustrates the design process map where designers need to go through analysis to synthesis and then finally reach to the decision level. Design is not a linear process; analysis, synthesis and evaluation/decision of a design process are required to allow for return loops from one activity to another. It is worth mentioning that in design process, analysis skills are required to understand the design problem

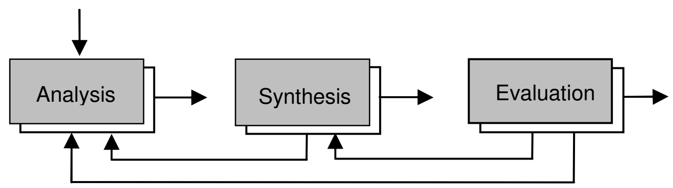

Figure 2. Design process map (Lawson, 2005)

to be solved and synthesis skills are mandatory to solve it.

A detailed study of an advanced iBIM project in Finland (Kiviniemi, 2011) indicated that the current design processes are based on tasks which define the required documents at different stages but not the needs of actual information flow, which results in missing some crucial information in the whole process. This led to the integration of process models to the actual design process and this approach is gradually attracting more interest from the researchers. An airport terminal has to accommodate a wide range of allied operations and facilities; the performance of any operation influences the other. Appropriate integration of the process model prior to the design process could uncover the relationships that exist between the space and the relevant functions, which could be missed in the traditional design approach.

3 PROCESS MODEL TO INDENTIFY SPATIAL REQUIREMENTS IN AN AIRPORT TERMINAL

The process of building design is as equally important as the standards or formulas of design. Analysis of business process models for an airport terminal provides significant information to understand the passenger movement as well as help to identify the spatial requirement of corresponding terminal operations and facilities. Business process modeling can be done in many ways and extensive documentation is available about various approaches. Among the available techniques, Integrated Definition (IDEF) and Business Process Modeling Notation (BPMN) are the two commonly used methods (C. Eastman, et al., 2008). The Airports of the Future (AotF) project (AotF, 2010) is examining the flow of passengers at Australian airport terminals and appropriate methods to facilitate these flows. Business process modeling is being used across the AotF project to analyse the flows of passengers at in-bound/arrival and out-bound/departure facilities.

Passenger movement within various terminal facilities provides important information to allocate functional spaces, but has not been traditionally integrated within the terminal design process. The current study introduces a means of extracting relevant information from business process models to augment the airport terminal design process. The current research examines the BPM of Brisbane International Airport, Australia to demonstrate how BPM could be utilized to extract useful information for use in the design process.

3.1 *Examining departure activities of Brisbane International Airport*

The departure activities of Brisbane International Airport occur at levels four and level three. Level four houses Check-in facility and discretionary facilities, whilst level three houses security check-in, customs and immigration, discretionary facilities and departure lounge, whilst. Analysis of the departure activities of Brisbane International Airport shows that the total departure could be classified into two major categories – mandatory activities and optional activities. A high-level description of the departure activities is presented in Figure 3. The mandatory processes of departure area are terminal entry, check-in, security, customs & immigration and boarding area. Discretionary activities including oversize luggage deposit, shopping, restaurant, toilets, ATM machines, internet kiosks etc. have been considered as auxiliary/optional activities.

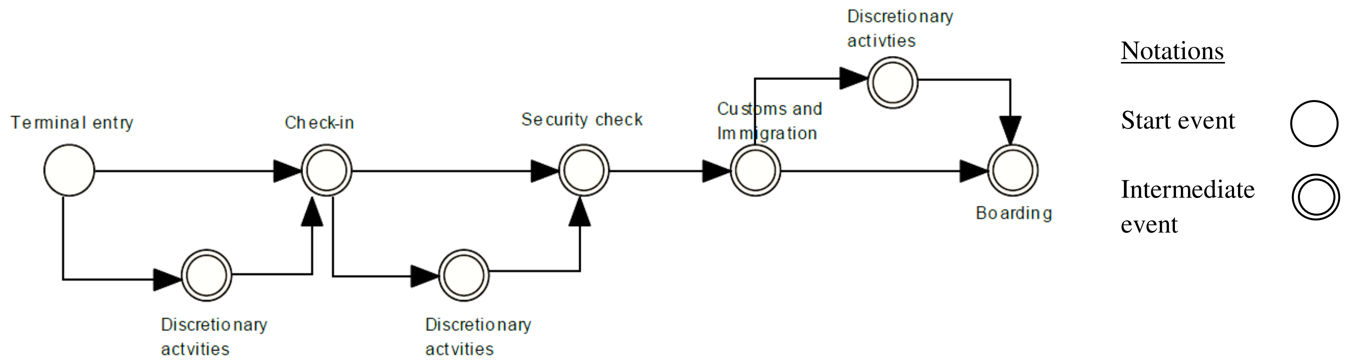

Figure 3. Departure activities of airport terminal

3.2 *Spatial requirements*

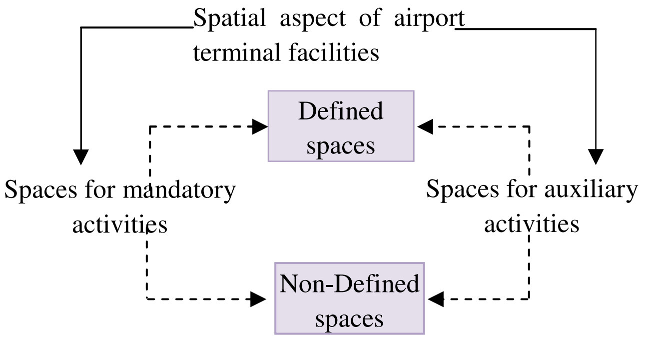

Figure 4. Classification of activities according to spatial requirements

In a typical airport terminal, designed with several in-bound and out-bound facilities, some facilities ideally should be grouped in a close proximity, whereas grouping of some other facilities are not essential. As mentioned in Section 3.1, a high level description of the departure area segregates the facilities under two major activities. Analysis of the process models also identified that of some of these activities are performed in defined spaces and some are performed in non-defined spaces. Decomposition of the mandatory activities into sub categories helps to classify the passenger activities required to be performed in a defined or non-defined area. For example, according to the BPM some passengers re-arrange their luggage just after entering the terminal, some may re-arrange their luggage (such as, for taking out overweight items) while performing check-in activities near the check-in counter. In both cases the activity could be performed anywhere at the departure hall –at the entry hall or at the circulation area. On the other hand, check-in facility is a defined entity with several counters along with specified area for queuing. Considering all the activities that take place in a passenger terminal, Figure 4 shows a high level classification of activities according to the spatial requirements. The current research is aimed to devise a technique to find an optimal layout for check-in area considering spaces for both mandatory and auxiliary activities.

4 PROCESS MODEL TO SPACE ALLOCATION MODEL: CHECK-IN FACILITIES

Passenger movement from landside to airside may be expressed using a series of areas, which are bounded and non bounded by a physical volume. In design, rooms or spaces to be adjacent in a plan allow people to directly access from one to the other, which is commonly referred to as 'adjacency requirement'. The layout of the spaces according their required adjacency is a core activity in a design process. Typically, a space layout design process within a building, involves two sets of design criteria – the constraints and *desiderata* (desired or wanted solutions or features) (Galle, 1981). The design solution of a floor plan layout should satisfy all constraints and fulfill as many *desiderata* as possible. Analysis of available BPM should allow us to identify both the required and desired adjacencies and hence should facilitate in the preliminary design process.

4.1 *Existing BPM to modified BPM (mBPM)*

The available process model of the check-in area of Brisbane International Airport (BNE) captures all the detail activities that occur from both sides e.g. an airport personnel and a passenger. The current research requires a simplified version of the process model that does not necessarily include all the detail activities that take place during an entire check-in procedure; the main focus is the space requirement not to look at all the minor details which are already available in BPM. Section 3.2 illustrated a process to identify activities according to spatial requirements. A complete check-in procedure is composed of check-in counters, queuing area and area for auxiliary activities, such as, oversized baggage deposit etc. Again check-in counters and their corresponding queuing area can be divided into separate counters for various types of passengers e.g. business class, economy class and counters for the passengers who have already completed check-in through internet. As all the aforementioned activities take place in a one single check-in desk, mBPM therefore considers each check-in counter as a single activity.

4.2 *mBPM to architectural layout of check-in area*

The obtained adjacency information gathered from mBPM could be used to develop a preliminary floor layout plan for the terminal entry area. Considerable research works were carried out to develop a systemic method to transform an adjacency graph into a physical floor plan. Graph theory (Harary, 1969) is a branch of mathematics and its implication in architectural design problem has an extensive research history since 1964 (Levin, October 1964). Graphs are made of vertices and edges; the attributes represented by the vertices and the edges of a graph is usually defined by the users (Roth & Hashimshony, 1988). The use of graph theory allows to maintain the required relationship between activities and as well as provides a systemic progression from the given adjacencies data towards achieving a formal layout (Hashimshony, et al., 1980). The first step towards achieving an optimal layout of a floor plan is to create a graph representation from the required adjacency data of the various activities. The developed mBPM provides required information related to adjacencies that should be maintained in the design process.

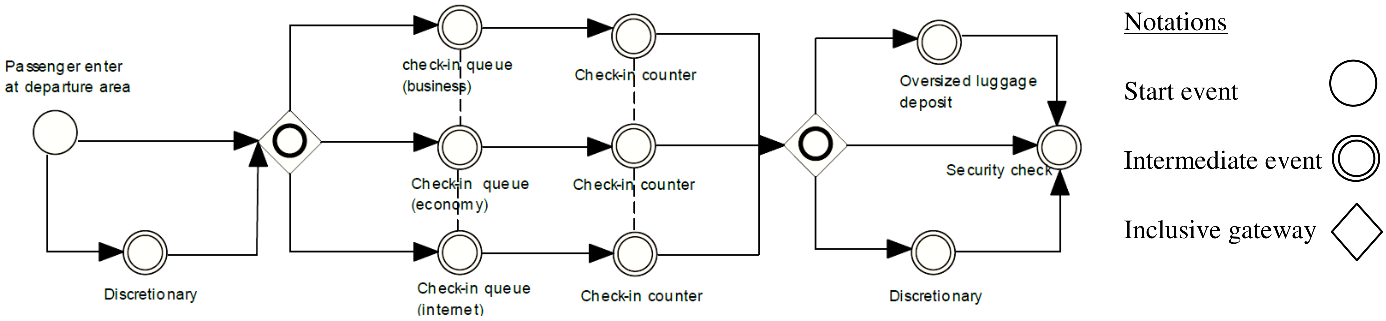

Figure 5. modified Business Process Model (mBPM) for the check-in process

The mBPM presented in Figure 5, is the modified version of the examined BPM and has been generated using the "Enterprise Architect" software with Business Process Modeling Notation (BPMN). The mBPM shows that once a passenger enters into the departure area an 'event' started then s/he enters into a decision point, which is represented as 'inclusive gateway' (used in a situation where one or more alternative could be taken) in the model. From that point a passenger can either join to the check-in queue or take a discretionary act and then can join to the check-in queue. After completing the check-in procedure from the check-in counter the passenger comes to another decision point. If the passenger needs to deposit any oversized luggage s/he moves on the oversize luggage counter or can go straight to the discretionary facilities or may moves on to pass through security check-in. The proposed mBPM shows the spatial adjacency between various activities of the check-in process in a simplistic manner.

4.2.1 *Step 1: mBPM to graph layout*

Each activity of the check-in process represented in mBPM is considered as vertex/node and the connections between those activities are considered as edges/link. The followings are the notations used in the graph representation shown Figure 6,

EN	Entry
DS1	Discretionary area 1
BCQ	Business check-in queue
ECQ	Economy check-in queue
ICQ	Internet check-in queue
C1-C5	Check-in counters
SCQ	Security check-in
DS2	Discretionary area 2

It is obvious that there are several intersections of links in the developed graph, which categorizes this as a non-planar graph according to the definition of graph theory. When the connecting links between the nodes intersect each other it is called non-planar graph and if the connecting links do not cross each other is called planar graph. Several algorithms and mathematical equations (Harary, 1969) are available to check the isomorphism of graphs. The simplest way to explain graph isomorphism is to say that one graph can be re-arranged to look like the other one. Often two graphs may look completely different on paper, but are essentially the same from a mathematical point of view. Two graphs G and G' are said to be isomorphic to each other if. The adopted graph in Figure 6 is an isomorphs' to $K_{3\ 3}$. According to Kuratowski's theorem (Harary, 1969) $K_{3\ 3}$ graph does not meet the Euler's formula of planarity, that why any graph contains subdivision of $K_{3\ 3}$ is not planar.

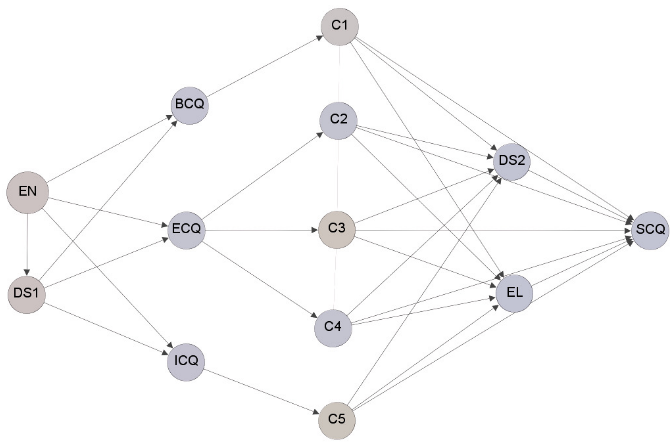

Figure 6. Graph representation of check-in facilities

Roth (1988) identified that the transformation of a graph into a floor plan is a tedious process. If the generated plan has to be of one level then the graph representing it has be a planar one. To transform a graph into a floor plan layout, the developed non-planar graph is then going to be transformed into a planar one.

4.2.2 *Step 2: Turning the non-planar graph into the planar one*

A non-planar graph could be turned into a planar one by using following methods (Hashimshony, et al., 1980):

1. By adding vertices at the unavoidable crossing links.
2. By cancelling some of the links forming the unavoidable crossings.

The current research work adopted the method No. one. Adding vertices to a graph means addition of a functional unit in the plan. Here addition of an extra vertex considers addition of a circulation area inserted between nodes connected by crossing links. In Figure 7, two circulation areas DH1 and DH2 have been inserted in terms of departure hall to the graph. As a result, the direct connection between the crossing links has been interchanged with an indirect one: a connection through a circulation area. The added circulation area DH1 avoids the crossing of links (DS1, BCQ), (DS1, ECQ) and (DS1, ICQ). And added vertex DH2 avoids the series of crossing of links (C1, EL), (C2 , EL), (C3, EL), (C3, EL), (C4, EL), (C5, EL), (C1, DS), (C2, DS), (C3, DS), (C4, DS) and (C5, DS) in Figure 6. The detail mathematical description of the adding circulation areas has not been explained in this paper.

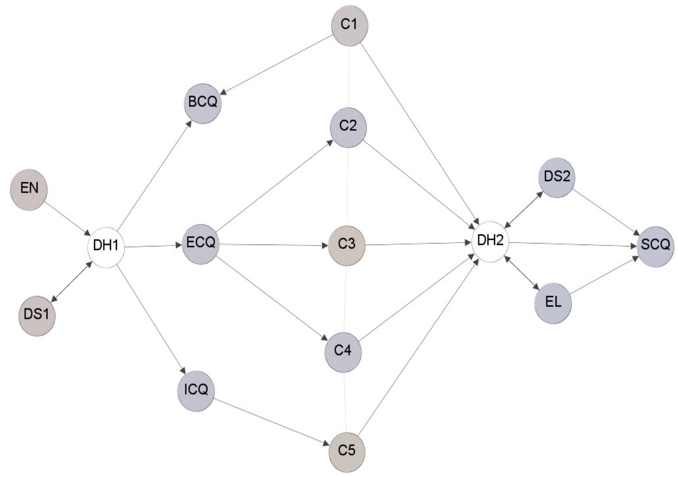

Figure 7. Turning non-planar graph into planar (G) using intersecting vertices

4.2.3 *Step 3: Dual graph as requirement diagram*

The next level is to represent the graph layout of the check-in area into a possible floor plan dual. In the current work dual graph is used as a representation for the floor plan. Grason (1970) identified that a graph can produce different geometric realization. Each different realization of a dual graph corresponds to a different layout of floor plan can be generated from the graph. A possible representation of the floor plan dual has been represented in Figure 8. According to the definition of dual graph, the graph **G**' in Figure 8 is dual to the given graph **G** of Figure 7. The dual graph **G**' considered each node of the graph **G** as activity and the link between each node is the desired adjacency between those activities. But the fact is that the developed graph is not a unique plan, there is still a great variety of possible architectural solutions are available depend on the requirement of the total process.

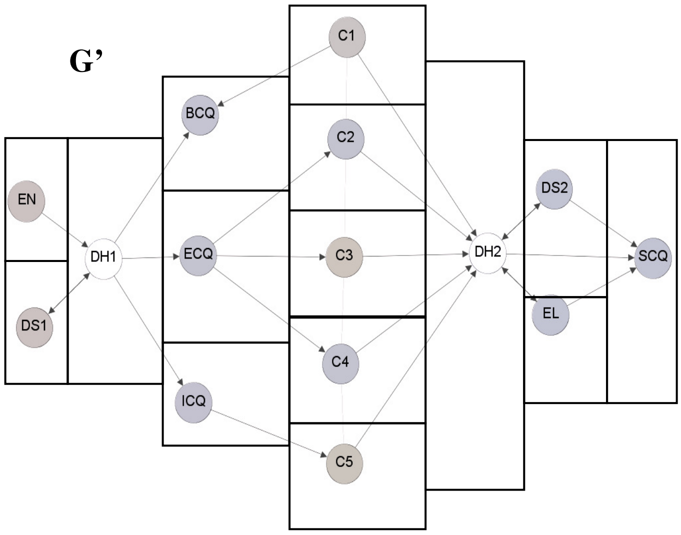

Figure 8. A possible representation of floor plan layout

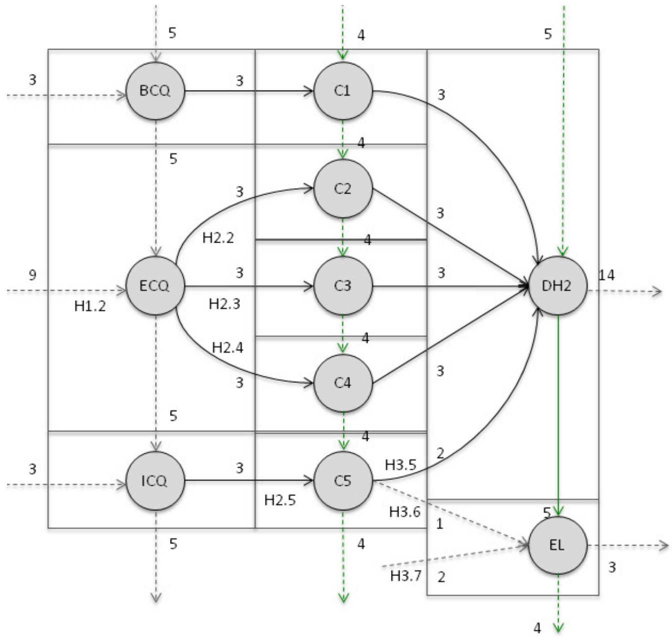

Figure 9.

4.2.4 *Step 4: Non-dimensioned to dimensioned layout*

This stage of the process follows the method described by Grason (1970). Using the centre three columns from Figure 8 (to keep the figure simple), a rectangle is placed around each activity and the edges of the rectangles are aligned to suit the designer (Figure 9). A link is drawn from each node to every other node that shares a boundary with it. This is the dual of the "wall graph". In Figure 9, all links that are already present in Figure 8 are drawn as solid, while links that are required just to complete the dual graph are drawn dashed.

Two separate graphs are generated if the links corresponding to the vertical wall segments are separated from the links for the horizontal wall segments. The application of Kirchhoff's current law "The sum of all directed currents going in to a node must be zero" then gives a set of linear equations that define the possible wall lengths across the entire layout. For example, at node ECQ for the vertical wall segments:

H1.2 = H2.2 + H2.3 + H2.4

Once the key dimensions are given, the other dimensions are automatically determined. So that, if H1.2 is given as 9m, H2.2, H2.3 and H2.4 must add up to 9m. Conversely, if H2.2, H2.3 and H2.4 are given as 3m each, then H1.2 must be 9m.

5 CONCLUSION

The current paper proposed a method to accumulate design related data from BPM to contribute to the architectural design process of airport terminal. In particular, the proposed method aimed at helping the designers to develop a systemic design approach to the initial physical layout of airport terminal facilities. In general, a layout deals with object (building facilities, rooms etc) and their relationships, where use of graph theory has been employed to utilize the initial space allocation data from the modified process model. The process model of airport terminal provides an essential information flow to the airport terminal design process. This will support the development of more integrated design practices and share a great benefit of design process.

6 FUTURE WORK

The future research findings are expected to support new design approaches and as well as re-configuration of existing passenger terminals with more flexibility. The results from initial studies have provided the basis for analyses of the flexibility of airport terminal design against possible future scenarios. In future parametric spatial models of the check-in area will be developed to evaluate flexible design parameters qualitatively and quantitatively. The results expected to be used as a reference model for further design development of airport terminal.

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